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**PROJECT 2WM**

# **SUMMARY REPORT**



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**March 1982**

South Florida Water Management District  
P.O. Box V  
West Palm Beach, Florida 33402

## BACKGROUND-OBJECTIVES

This report contains a brief summary of the cloud-seeding program conducted in south Florida from August 4, 1981 to September 30, 1981.

On July 20, 1981, the Governor of Florida declared south Florida a "Drought Disaster Area" based on the record low water levels in Lake Okeechobee and much lower than normal rainfall throughout the area.

The South Florida Water Management District (SFWMD) Governing Board approved a weather modification program in late July, 1981 to augment rainfall and improve Lake Okeechobee water supplies. The objectives of Project 2WM were:

- Raise groundwater levels throughout the designated Project Area and provide for increased water levels in the Lake.
- Seed cumulus clouds in the Project Area with silver iodide to achieve maximum beneficial rainfall increases while providing for maximum safety for all people and property that may be affected.
- Acquire adequate rainfall data to allow for the best evaluation of results at minimum cost.
- Keep the public informed as to the progress and results of all cloud-seeding operations.

The Project Area was defined as being made up of all major drainage basins into Lake

Okeechobee. A secondary area was to be seeded only if there were no cumulus clouds in the primary area.

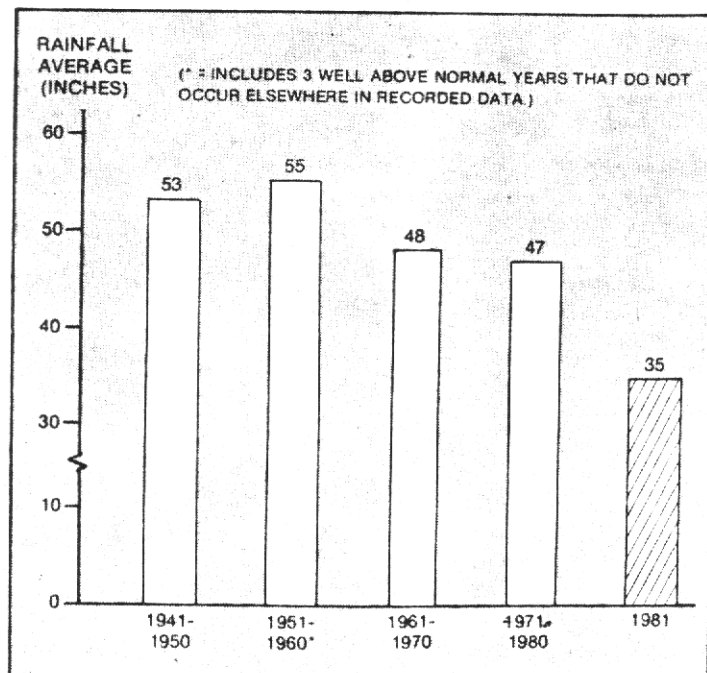
The emergency nature of the Governor's Proclamation allowed overflying other WMD boundaries. Seeding operations extended over the SJRWMD once the project was underway, based on a mutual agreement.

Project 2WM was designed based on the results of Project FACE conducted by the National Oceanic and Atmospheric Administration (NOAA) from 1970 to 1980. 2WM operations were done as close to "FACE" methods as possible, including seeding agent, rates and cloud seedability decision-making.

A number of different evaluation methods were used to estimate that from 254,000 to over 350,000 acre-feet of rainfall was added to Project Area watersheds, as the result of cloud seeding. The daily variation in the Lake's water level prevents accurate estimates of increased stage levels, however approximately 41,000 to 56,000 acre-feet were added to the Lake due to cloud-seeding.

*Special recognition is given to the NOAA team, headed by Dr. William Woodley, without whose support this project could not have been done.*

Rainfall over the Kissimmee River Valley has been lower than normal for the past ten years. This average is also much lower than all previous historical records show.



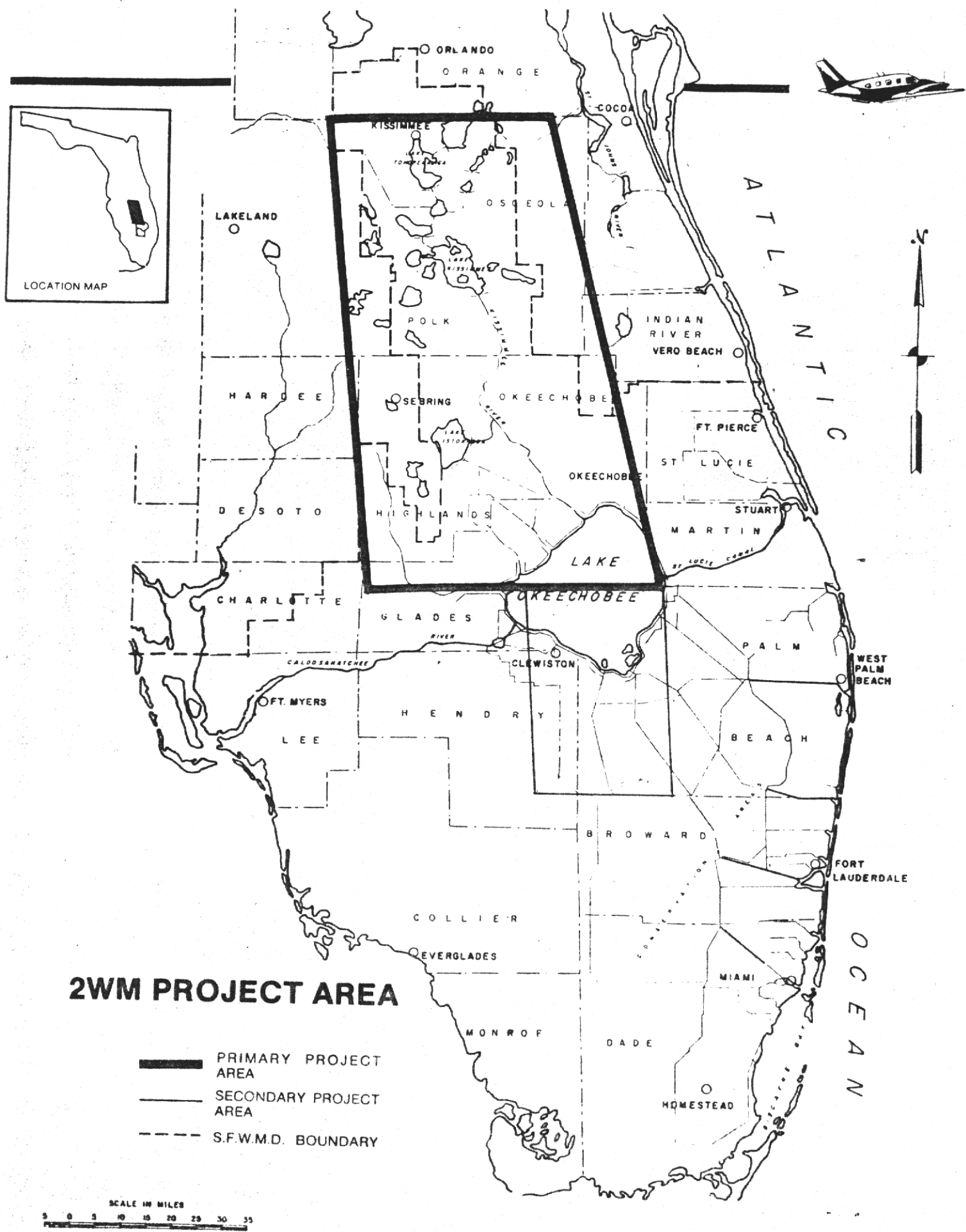
# DATA CATALOG & REFERENCE



As a result of the 2WM Project, the SFWMD has available data on weather modification that may be of interest to various public or private sectors. This information is identified in the table below.

TYPE OF INFORMATION	FORMATS	DATES AVAILABLE
Pseudo-Adiabatic Charts and supporting meteorological data. <i>(Includes radiosonde printouts, 500MB analysis, surface analysis chart and cumulus cloud model printout)</i>	Actual charts and printouts for each day of project.	August 4-Sept. 30, 1981
Radar rainfall intensity displays <i>(6 intensity levels over project area)</i>	VHS Tape Cassettes	Most days in project period.
GOES Satellite Photos - Laserfax <i>(10" x 11" Black/White photos of cloud cover over Florida)</i>	Photographs	6 to 8 photos per day starting August 10, 1981
Project Flight Logs and Backup Data <i>(Pilot/Meteorologist event identifications, altitudes, temperatures and water content in seeded clouds, and ground radio logs)</i>	Daily Tabulations	Full Project Period
Seeding Plot Charts <i>(Seeding locations for each day)</i>	Daily Maps	Full Project Period
Rainfall Results and Data <i>(Rainfall tabulations for 13 basins for June through September of 1976, 1980 and 1981. Locations and maps of all rainuages used. Tabulated comparisons of each year's rainfall).</i>	Maps, Tables and computer printouts.	Full Project Period
Water Quality Assessments. <i>(Site locations, methods and analytical results of sampling runs)</i>	Written Report	Before, during and after Project Period
On Station Photographs <i>(Taken by flight crews on most missions)</i>	Polaroid Photos	Selected days during Project Period
Public Information Assessment <i>(Narrative report on activities and results.)</i>	Written Report	For Project Period
Video Documentary Footage <i>(In-flight operations, ground operations, various aspects of seeding missions).</i>	VHS Tape	For Project Period
Document Bibliography <i>(Over 250 references for weather modification projects, background, history, state programs etc.)</i>	Books, Reports and Data	N/A





## SYSTEMS USED

All flight systems were provided by the contractor selected to conduct project 2WM operations.

Three twin-engine aircraft were used (1 Cessna 421 and 2 Piper Navajo's). These were equipped with seeding racks and controls, and meteorological instruments. Aircraft conducted both seeding and reconnaissance operations.

Each aircraft had the ability to fire up to 200 silver iodide flares which were controlled from inside the aircraft. Onboard records were kept of each flare fired in relation to the aircraft's position within the project area.

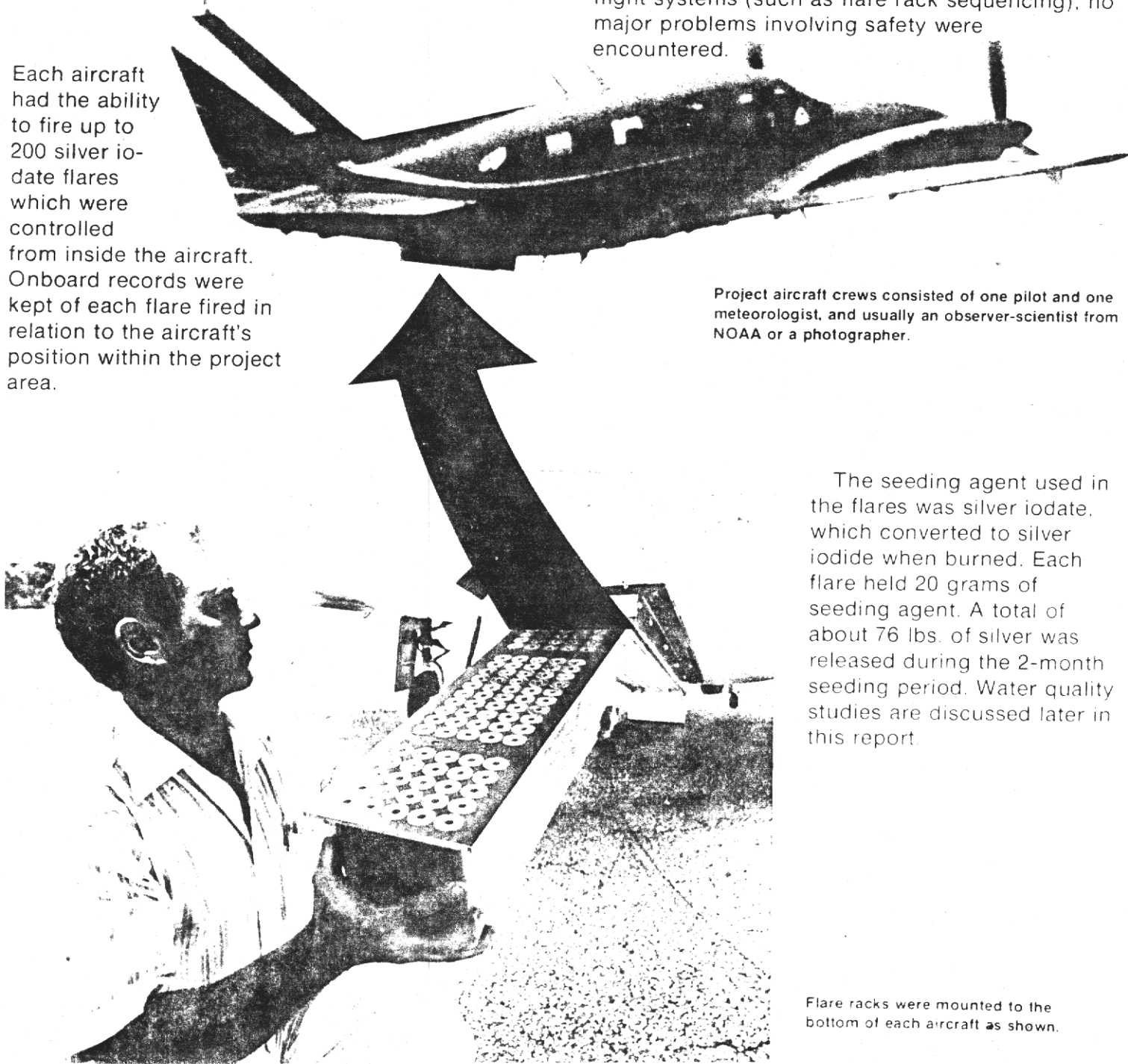
Instruments onboard each aircraft monitored liquid water content and cloud temperatures. A Datel data recorder provided these data for translation by the SFWMD HP-1000 computer for post-flight analysis. Many of the instruments were also used to determine the seedability of clouds during each day's operation.

Although minor malfunctions occurred with the flight systems (such as flare rack sequencing), no major problems involving safety were encountered.

Project aircraft crews consisted of one pilot and one meteorologist, and usually an observer-scientist from NOAA or a photographer.

The seeding agent used in the flares was silver iodide, which converted to silver iodide when burned. Each flare held 20 grams of seeding agent. A total of about 76 lbs. of silver was released during the 2-month seeding period. Water quality studies are discussed later in this report.

Flare racks were mounted to the bottom of each aircraft as shown.





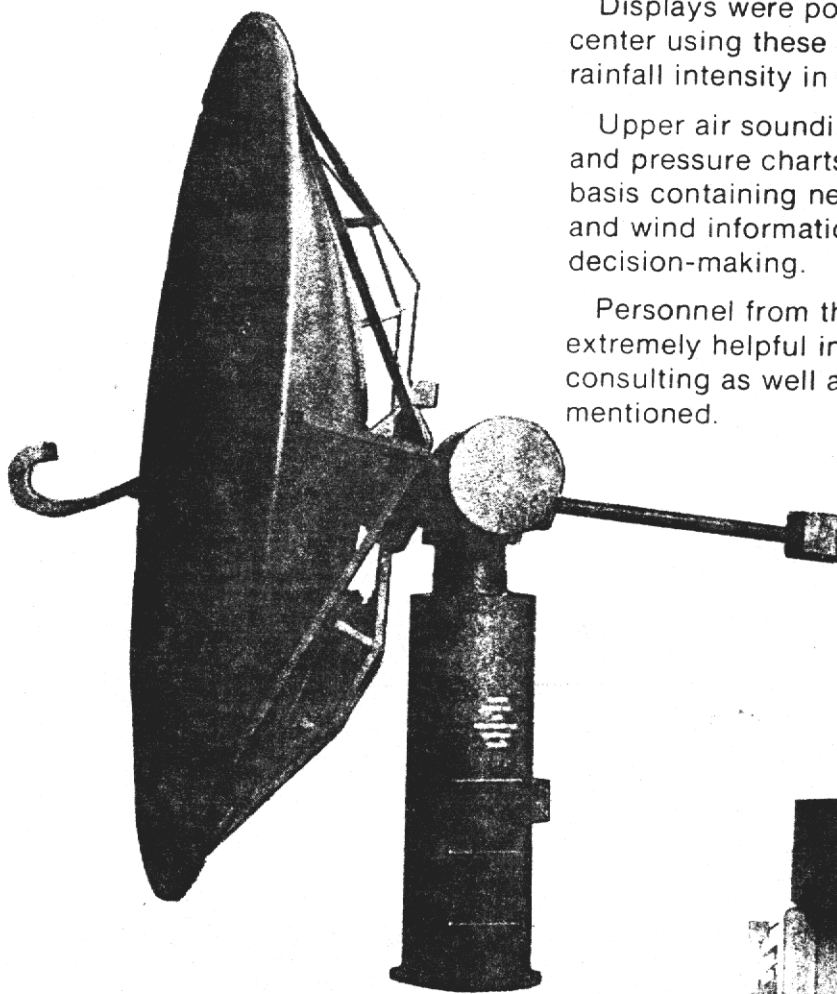
The National Weather Service (NWS) at Palm Beach International Airport supported Project 2WM with a number of essential services.

Radar outputs from the NWS WSR-74 S-Band meteorological radar system provided basic data for daily decision-making and for tracking cloud formations during all seeding operations.

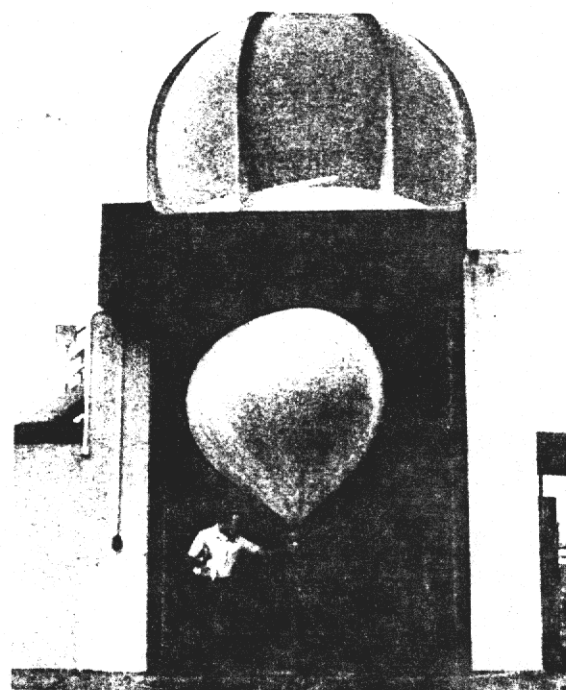
Displays were possible at the project control center using these radar signals, that showed rainfall intensity in six different levels.

Upper air soundings, surface analysis charts and pressure charts were all provided on a daily basis containing needed temperature, moisture and wind information for cloud-seedability decision-making.

Personnel from the Palm Beach NWS were extremely helpful in furnishing meteorological consulting as well as the data previously mentioned.



The NWS WSR-74 S-Band radar was a key element of the ground system used to monitor and control seeding operations.



The NWS Radiosonde provided high-altitude weather information on a twice daily basis.



## COMMUNICATIONS AND CONTROL

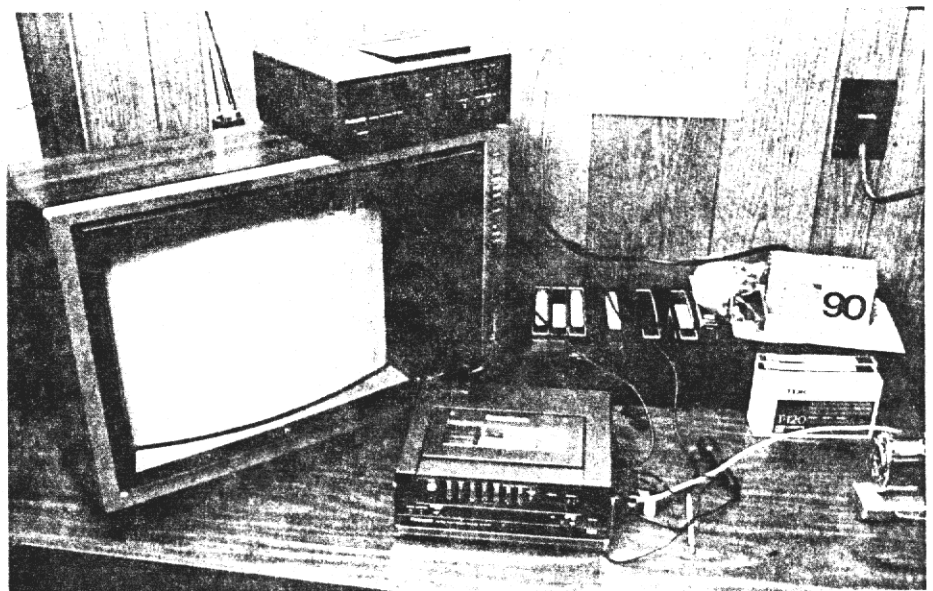
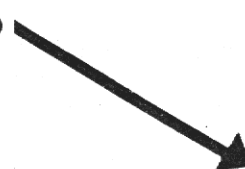
The 2WM Operations Control Center was the focal point for directing the two month seeding activities. This was done through the use of the systems and methods shown on the facing page.

Throughout the project, major emphasis was placed on the safety of the airborne operations and the actual seeding that was done. Specific rules were established to guide when seeding could be done, based on weather conditions in the project area. This was done to prevent creation of excessive rainfall that might risk people or property in the seeded areas.

Direct lines of communication were established and exercised daily with the FAA (Miami) and USAF (Avon Park Bombing Range). No 2WM aircraft were launched without notification and clearance from both these agencies since flights were in a high traffic corridor as well as a significant part of project air space being located over a Restricted Bombing Zone.

Complications due to the nationwide air controllers strike, which began several days before the first 2WM operational flight, did not occur due to the willingness and cooperation of the remaining controllers.

LASERFAX 550  
SATELLITE PHOTO  
RECEIVER



The video data acquisition system allowed real-time records to be made of rainfall intensities measured by the NWS radar.



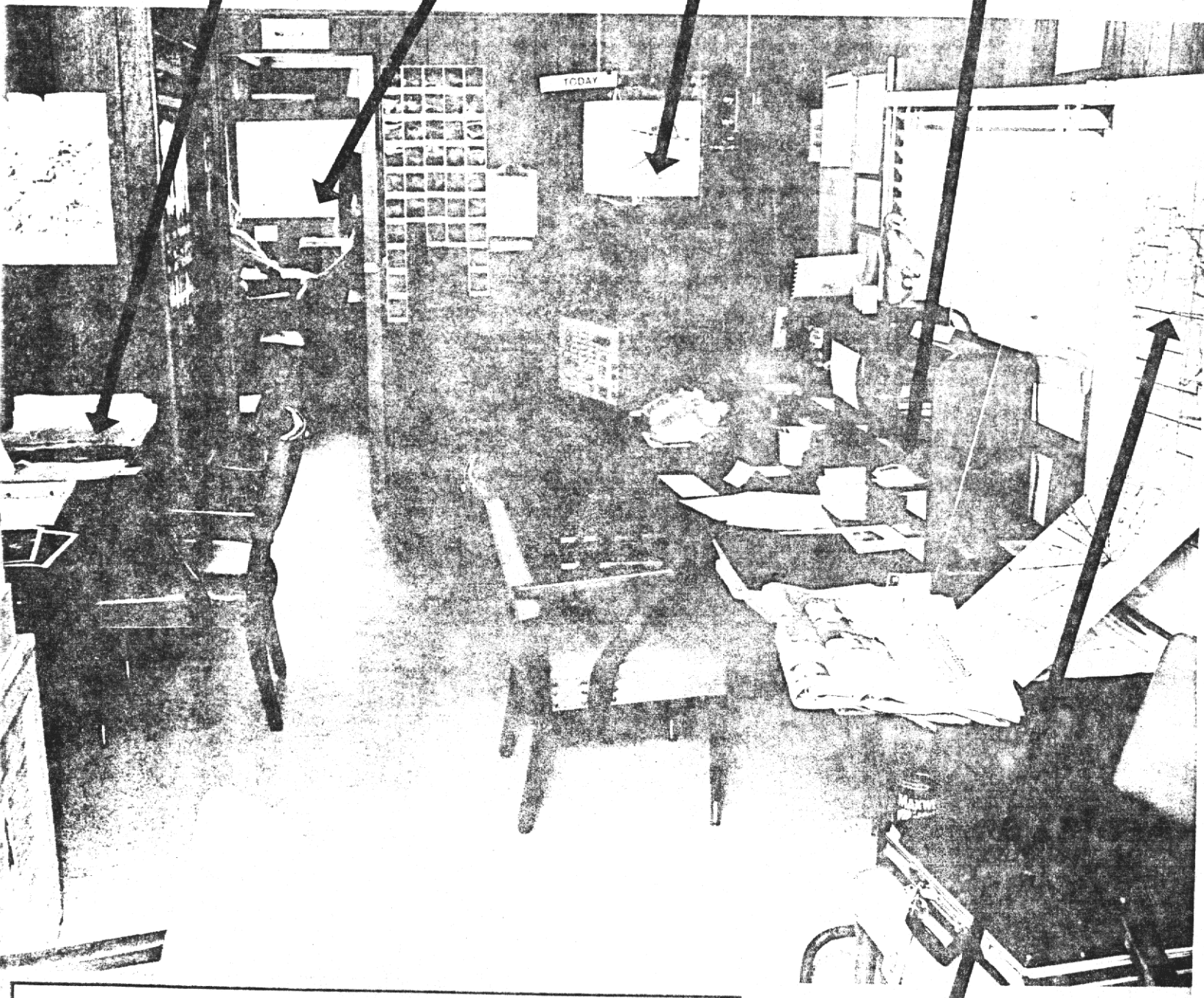


BRIEFING/  
DEBRIEFING  
AREA

WSR-74S  
RADAR  
DISPLAY  
& CONTROLS

GROUND-TO-AIR  
COMMUNICATIONS

METEOROLOGICAL ANALYSIS  
SECTION



**OPERATIONS CONTROL CENTER**  
(West Palm Beach)

OPERATIONAL  
PLOTTING  
& CONTROL  
SECTION

## DATA ACQUISITION

The conventional raingauge network that existed in the Project Area prior to August 1981 was the basic means of collecting rainfall data during Project 2WM. A total of 383 gauges, in and out of the project area, were operated by the following agencies:

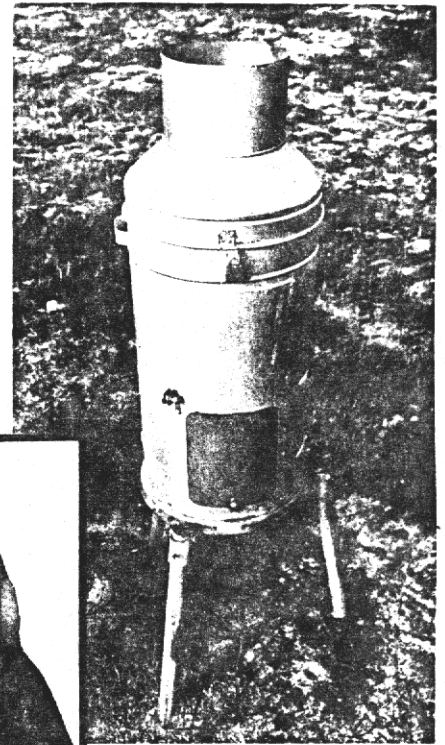
- NOAA
- Corps of Engineers
- U.S. Geological Survey
- Agricultural Research Service
- Florida Division of Forestry
- SJRWMD
- SWFWMD
- SFWMD

These were augmented by 109 "fence post" type raingauges installed for Project 2WM and manned by volunteer local residents

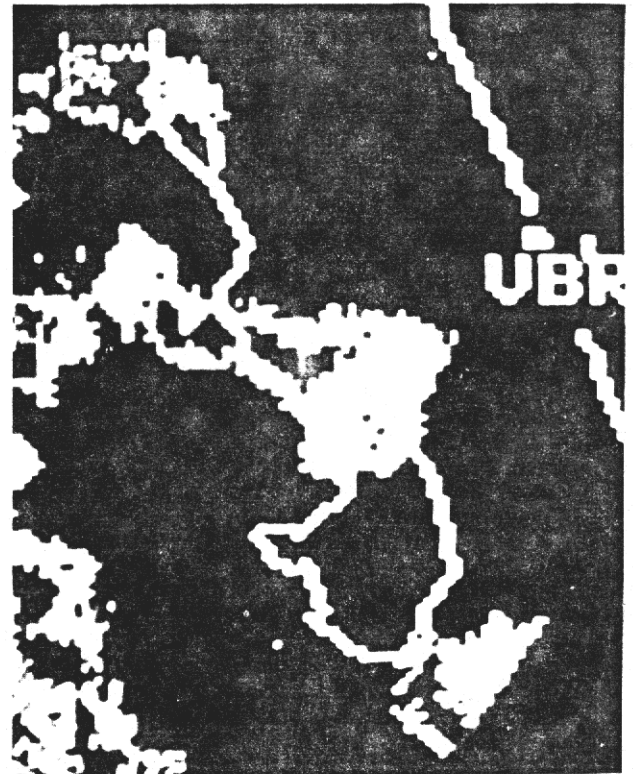
Data from the conventional network was obtained by weekly and monthly reports, bi-weekly helicopter trips and daily radio readings.

The Project Area was divided into 13 basins that represent the major watersheds into Lake Okeechobee. Locations of each raingauge and the actual data obtained during the project period are available in a series of maps, tables, and computer printouts. This is discussed at the end of this report.

The Weather Service radars were used for tracking cloud cell development and motions. Correlations between radar returns and ground rainfall measurements are covered under the section on "RAINFALL ANALYSIS". Radar data provided an indication of rainfall intensity through color displays, in six levels of rainfall rate.



The Belfort Weighing Raingauge was the basic ground system used. The plastic "Fence post" raingauge is shown to the left.



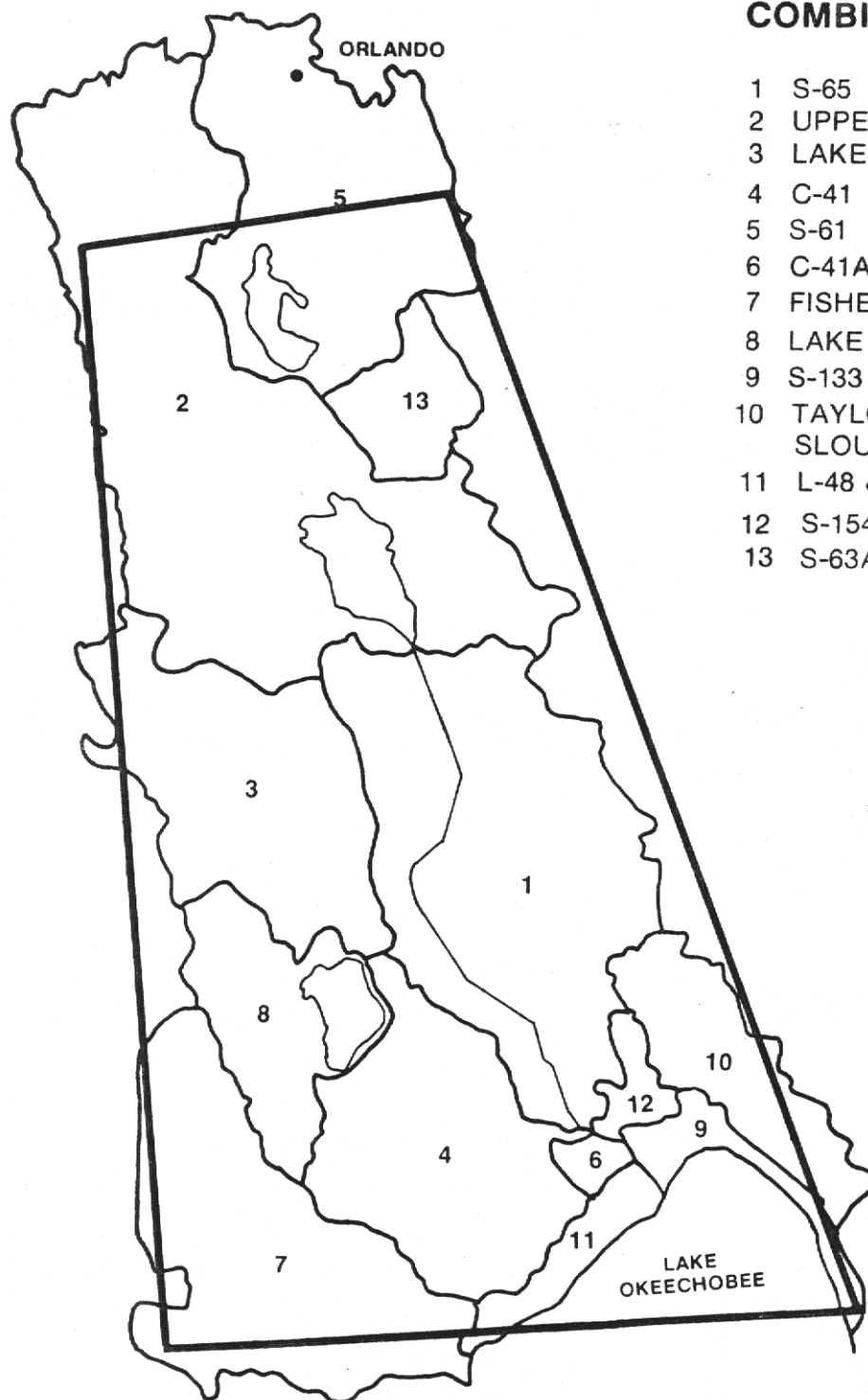
A radar display of August 24, 1981 showing three rainfall intensity levels over the Kissimmee Valley.



## 2WM PROJECT AREA

## COMBINED BASIN MAP

- 1 S-65
- 2 UPPER KISSIMMEE
- 3 LAKE ARBUCKLE
- 4 C-41
- 5 S-61
- 6 C-41A
- 7 FISHEATING CREEK
- 8 LAKE JACKSON
- 9 S-133
- 10 TAYLOR CREEK-NUBBIN SLOUGH
- 11 L-48 & L-49
- 12 S-154
- 13 S-63A



Photos from the GOES satellite, orbiting over 19,000 miles above the earth were used to locate cloud formations and track movements on a daily basis.



## OPERATIONS

A standard sequence was followed each day during Project 2WM. The main activities are shown in the set of small photos, and are all directed towards making a daily decision on whether there are suitable clouds for seeding in the Project area.

When there was a GO decision, aircraft were launched from the Palm Beach or Stuart airports. Most days saw two planes conducting seeding operations, on other days a single aircraft was used for reconnaissance when there was some question as to cloud suitability.

When the seeding aircraft arrived on station, communications were maintained with the Control Center and other seeding aircraft. Most missions lasted about 3 hours, although 4-5 hour operations were also done.

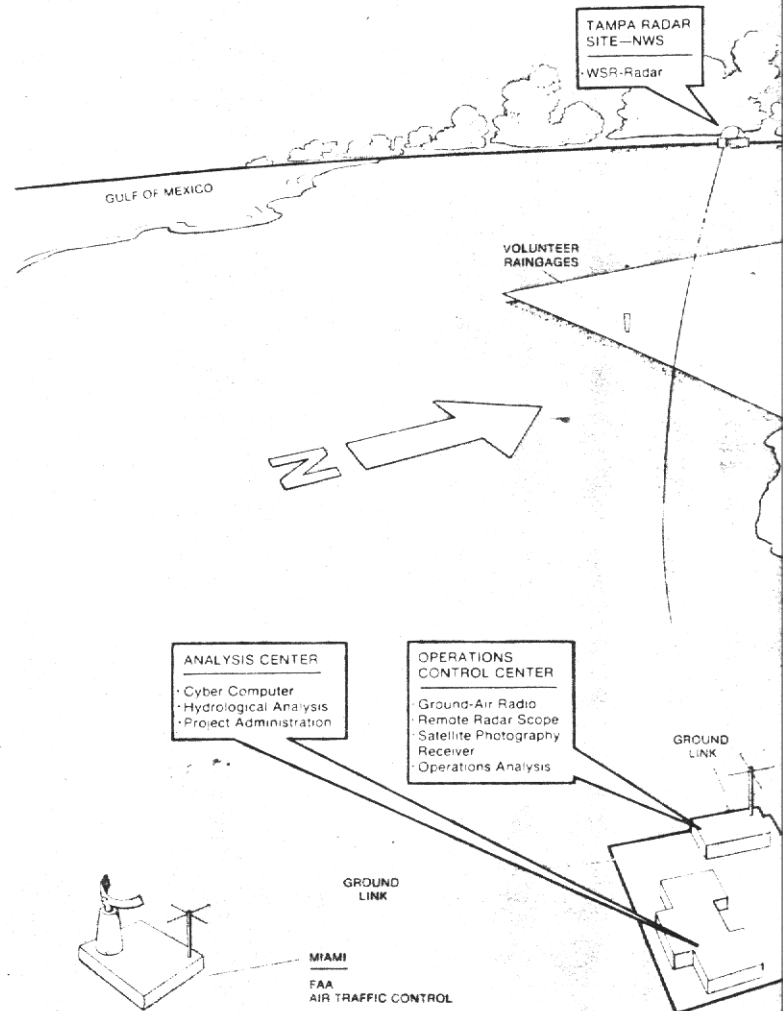
Project aircraft used the seeding technique from "FACE", which consisted of flying through the upper part of cumulus clouds, colder than  $-10^{\circ}\text{C}$  at their tops. Flares were fired into updraft regions which contain supercooled water droplets. The millions of microscopic sized silver iodide crystals produced by this burning convert the water droplets into ice crystals, which grow and fall from the cloud turning to raindrops as they pass through the freezing level.

Heat is also released by the droplets as they freeze, which causes the cloud to grow larger than it would naturally. This effect is known as dynamic seeding.

When there were no longer seedable clouds available in the Project Area, operations were stopped and a review was held at the control center.

*The staff of Palm Beach International Airport, headed by Richard Cleveland were very helpful throughout Project 2WM in assuring that systematic and safe operations were carried out*

THIS DRAWING SHOWS ALL THE MAJOR ELEMENTS OF PROJECT 2WM AND THEIR RELATION TO THE PROJECT AREA.



Project meteorologists and NOAA personnel combine all data received to decide a GO/NO-GO condition for each day of the Project period.





## RAINFALL ANALYSIS

There is no one scientifically accepted method for determining operational cloud seeding results. The reason for this is that rainfall is highly variable in time and space, and that seeding is conducted during periods when rain would occur naturally as well.

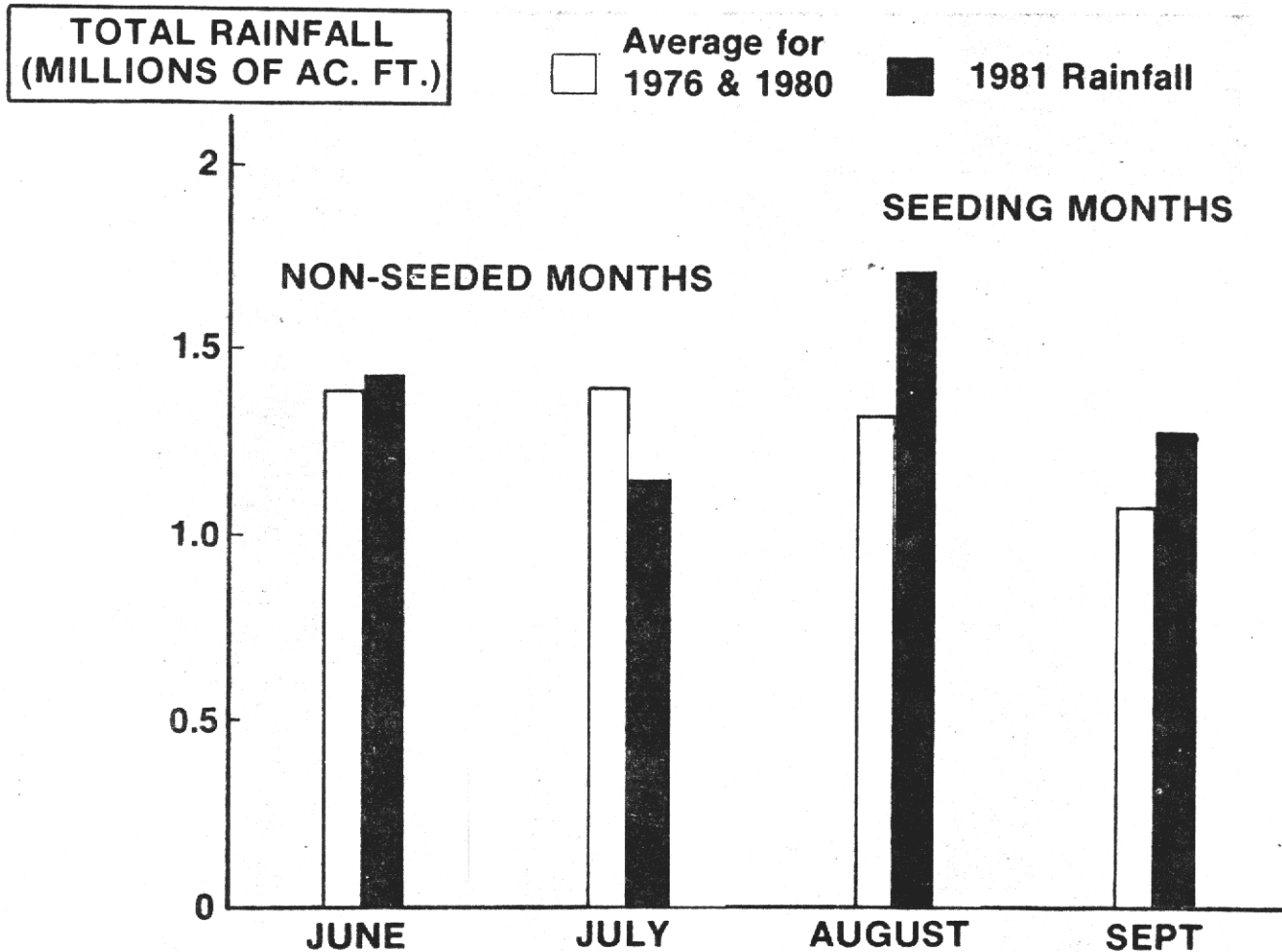
For Project 2WM, rainfall data gathered as previously discussed, was evaluated in several different ways, with a range of results provided. Comparisons were made of average rainfall during the project period and other time periods from historical records. Several seasons of seeding are usually required before effects can be statistically related.

Over 43,000 individual rainguage measurements from 1976 to 1981 were correlated for the 13

drainage basins feeding the Lake.

A computer program was used to estimate the percentage of total rainfall in a basin that was attributed to each separate rainguage. These amounts were totaled to obtain rainfall for an entire basin, and the acre-feet of rain over the basin's area.

An overall comparison was made of rainfall during the summer of 1981 and two recent wet seasons, where there was lower than average rainfall, (1976 & 1980). 25% more rain fell during August/September 1981, when there was seeding, than in June/July when there was no seeding. The repeatability of this trend can only be confirmed with additional seeding/no seeding comparisons.





A number of case studies were made to estimate cloud seeding results. A sequence of plots of radar displays have shown that seeded clouds, in general;

- Develop higher intensity rainfall earlier than non-seeded clouds.
- Produce rain for longer time periods than non-seeded clouds.
- Tend to merge and cover larger areas than unseeded cloud systems.

In addition, the amount of area covered by each day's seeding was measured based on the radar plots discussed above, and the wind speed and direction and seeding event locations recorded on daily operations logs.

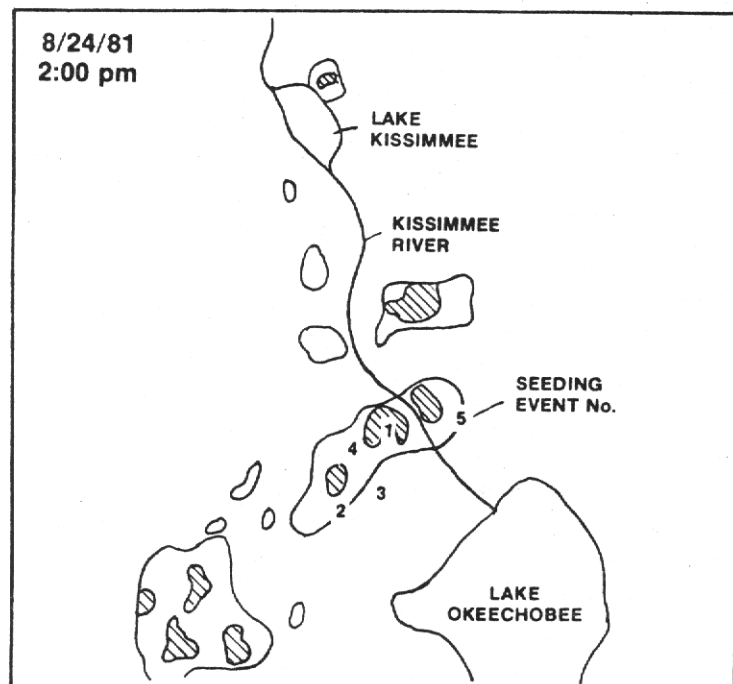
Rainfall over each basin was calculated from the computer model noted earlier in this section. Daily

tabulations for all parts of the Project Area that were seeded and unseeded allowed an estimate to be made of rainfall increases due to seeding.

Comparisons were also made with the first 3 days in August, 1981, before cloud seeding started, and 4 days from August 16 to 19, 1981, when Tropical Storm Dennis had not reached the Project Area, but caused operations to be suspended.

Both of these sets of days could be considered "control" days, where weather conditions were adequate for seeding, but none was done.

All comparisons are based on average rainfall amounts and are the only indications available with the number and type of data gathered on this Project.



- Level 1 = (0 to 0.2 inch/hr)
- Level 2 = (0.2 to 1.1 inch/hr)
- Level 3 = (1.1 to 2.2 inch/hr)
- Level 4 = (2.2 to 4.5 inch/hr)



Two radar tracings, made two hours apart during a seeding mission, show cloud system development before and after seeding was done. The cloud grew in size, intensity and area of coverage, and continued this pattern for about one hour more than the last time shown.



# RESULTS

## PROJECT 2WM-81 SEEDING SUMMARY

DATE	TOTAL FLIGHT HOURS	SEED DAY	NON- SEED DAY	ZONES SEEDED	# OF FLARES EXPENDED	COMMENTS
<b>AUG. 1</b>						
2	1.7				3	Pre-Project flight check
3	1.4				13	Pre-Project flare test
4	7.8	X		B,C,D	62	1st Day Operations-Project 2WM
5	9.0	X		A,B,C	109	
6	7.0	X		A,B,C	46	NOAA-Representative-Training
7	6.7	X		B	19	Poor Meteorological Conditions-RECON
8	8.9	X		A,B,C	171	
9	8.8	X		A,B,C,D	82	
10	9.6	X		A,B,C	228	Large Merged Systems - Laserfax Installation
11	10.5	X		A,B,C,D	297	
12	7.8	X		A,B,C,D	134	
13	7.2	X		B,C,D	220	Upper Air Ice Build-up
14	5.4	X		A,D	65	Poor Development
15			X		0	Operations Suspended - Tropical Storm Dennis
16			X		0	" " " " " "
17			X		0	" " " " " "
18			X		0	" " " " " "
19			X		0	" " " " " "
20			X		0	" " " " " "
21	2.7		X		0	RECON - No Seeding Opportunities
22	3.0	X		A	7	Late Development Day - High Winds
23	8.3	X		B,C,D	127	
24	11.9	X		A,B,C	344	Good Development
25	16.3	X		A,B,C,D	226	Adequate Wet Conditions - Late Day
26	2.0		X		0	RECON - No Seeding Opportunities - Disturbed
27	9.4	X		A,B,C,D	228	
28	6.6	X		B,C,D	42	Cirrus Shield Prohibiting Development
29	6.3	X		B,C,D	61	Dry Day - RECON/Seed
30	3.1		X		0	RECON - No seeding opportunities
31	3.2	X		D	5	Poor Development - Very Wet Day
<b>Sept. 1</b>	<b>9.8</b>	<b>X</b>		<b>A,B,C,D</b>	<b>265</b>	
2	4.0	X		B,C	40	
3	7.2	X		A,B,C,D	175	Late Day
4	6.6	X		A,B,C	175	
5			X			Too Dry - No Echo Development
6	7.8	X		A,B,C,D	268	
7	7.7	X		A,B,C,D	121	
8	5.1	X		A,B	46	Seeding + Ground Level Checks - RECON
9	5.8	X		B,D	30	
10	4.4	X		A,B	36	Dry - High Winds - Upper Atmosphere
11	2.1	X		B	4	Dry - Upper Level Wind Conditions
12	2.4		X		0	Very Dry - Winds
13	6.3	X		A,B,C,D	97	
14	4.9	X		A,B,C,D	101	Stable - Moist High wind
15	2.1		X		0	RECON - No seeding opportunities
16	4.0	X		A,B	61	
17	4.9	X		A,B,D	108	
18	2.8	X		A,B	98	
19			X		0	Very Dry - Poor Echo Development
20			X		0	Very Dry - Meteorological Conditions
21	4.5	X		B,C,D	70	Scattered Echos - Cirrus Shield
22	8.7	X		A,B,C	12	
23	2.0	X		A	26	Short Duration Echo Development
24			X		0	Very Dry - High Stability Index
25	4.0	X		A,C	38	
26	1.5		X		0	Very Dry Upper Air
27	2.6		X		0	RECON, Very Dry - Poor Conditions
28	2.6		X		0	Cloud Ceiling Below 10,000 Ft.
29	5.3		X		0	RECON/Photo - Ceiling @ 12,000 Ft.
30	3.2	X		B,C,D	19	Last Operational Day - 2WM-81
<b>TOTALS</b>	<b>286.8</b>	<b>39</b>	<b>19</b>		<b>4,339*</b>	<b>*Includes 16 pre-flight operation testing</b>



The total 2WM Project consisted of 39 days of seeding as shown on the left-hand page. Total rainfall estimated for all basins in the Project Area was about 2.9 million acre-feet. The increase in rainfall, as discussed under RAINFALL ANALYSIS ranged from 254,000 to 350,000 acre-feet, depending on which rainfall comparison was made.

This range represents 8.7% to 12% of the total Project Area rainfall during August and September of 1981. When all costs are considered, the cost ratio is about \$2.00 per acre foot of increased rainfall.

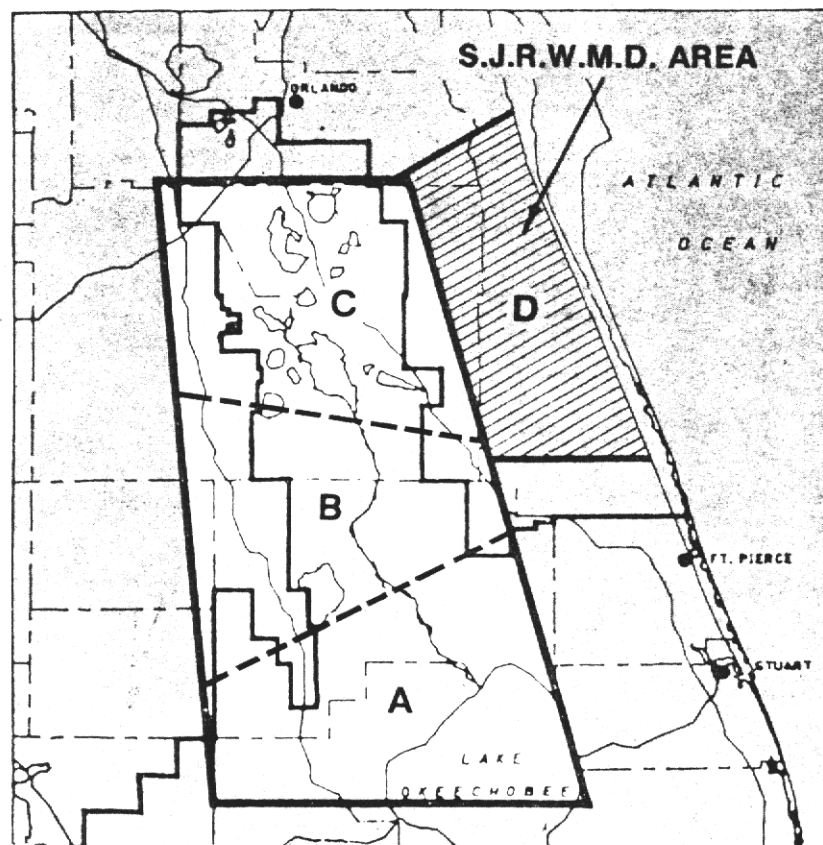
Since the soil and groundwater conditions in the Project Area were very dry before cloud seeding started, it is estimated that between 11% and 22% of the rainfall actually got into the Lake. This range is 41,000 to 56,000 acre-feet or from 38 to 51 million gallons per day of water, for an entire year.

This amount of water is enough to supply at least two cities the size of Hollywood in Broward County for one year.

A major priority of the 2WM Project was to evaluate the effects of silver used in the seeding agent on fresh water. Seven sites were established throughout the Kissimmee Valley, and were monitored before during and after the seeding.

The results of this monitoring, in brief were that;

- In all cases, silver concentrations were well below the 50  $\mu\text{g/l}$  "maximum allowable contamination" state standard for drinking water.
- Silver concentrations in south Florida's water exist primarily below 0.10  $\mu\text{g/l}$ , which is consistent with previous analysis done on NOAA's FACE programs.



Seeding missions were flown over four subsections of the Project Area for ease of coordination with the FAA and USAF. Section "D" covered part of the SJRWMD and used 612 flares during 19.2 hours of flight time. The use of flares and flight times for Sections "A, B and C" are shown in the table to the left.

## PUBLIC INFORMATION & LIAISON

From the very earliest discussion phase of Project 2WM, throughout the length of the project, public perceptions and information were considered high priority elements.

Among the actions taken were:

- Telephone surveys of agencies throughout the U.S. that had done cloud-seeding (to anticipate public and media problems).
- Contact with every city, county, and state agency that could be affected by Project 2WM. (to explain Project and obtain agreement when required).
- Contact with private interests in Project area, such as farming groups (to inform and answer questions).

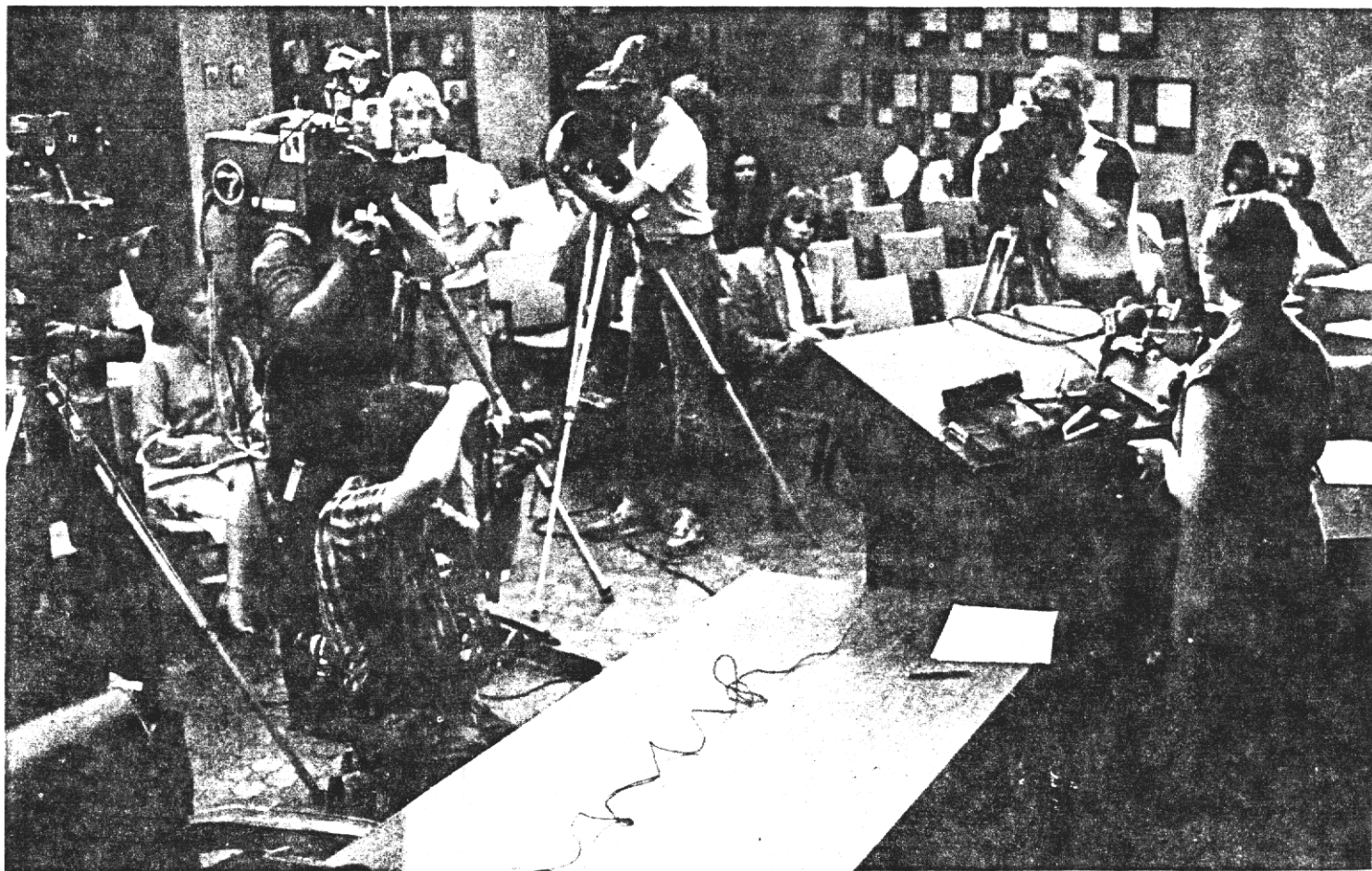
The Chief Meteorologist and Project Manager for the Contractor, John Walser provided the media with project details.



The SFWMD issued informational publications on cloud-seeding and initiated a special telephone answering service so the public and media could be informed on a 24-hour basis. Daily reports were issued on Lake stages, rainfall and cloud-seeding flight schedules.

A full review of public information and liaison activities is available, as discussed under the "DATA CATALOG".

The media showed great enthusiasm over the cloud-seeding project. This press conference introduced operational plans before the project began.





The SFWMD tried to meet the demand for information in an orderly and complete way. Briefings and news conferences were held before, during and after the Project, from July through December.

The media were provided special times during which all phases of the operation were visible and explained. Access to all levels of project management was provided from Governing Board members, to District staff to contractor personnel.

Observation flights were scheduled to give the media a feel for what a seeding mission consisted of. Each flight included a public information representative to answer questions and provide background information.

News coverage was thorough and accurate and helped explain to the public in south Florida the steps the SFWMD was taking to help alleviate the effects of the drought.

There were four complaints received about

The Governing Board received 6 briefings from July to December of 1981.



excessive rainfall during the Project period, within the Project area. In two of these cases, seeding had been done within twenty miles of the reported area. Operations in these areas were stopped as soon as the complaints were received. In the other two cases, seeding was not being done on the days reported.

In all responses to dealing with the public on Project 2WM, the most important consideration was given to their concerns and desires, over and above the operational requirements of the Project.

Among the tours provided was an inspection of the project aircraft and major systems. Project pilots and meteorologists provided much specific cloud-seeding experiences.





## PROJECT ORGANIZATION

Project 2WM functions were conducted by three major organizational elements designed to carry out an emergency program on an accelerated time scale.

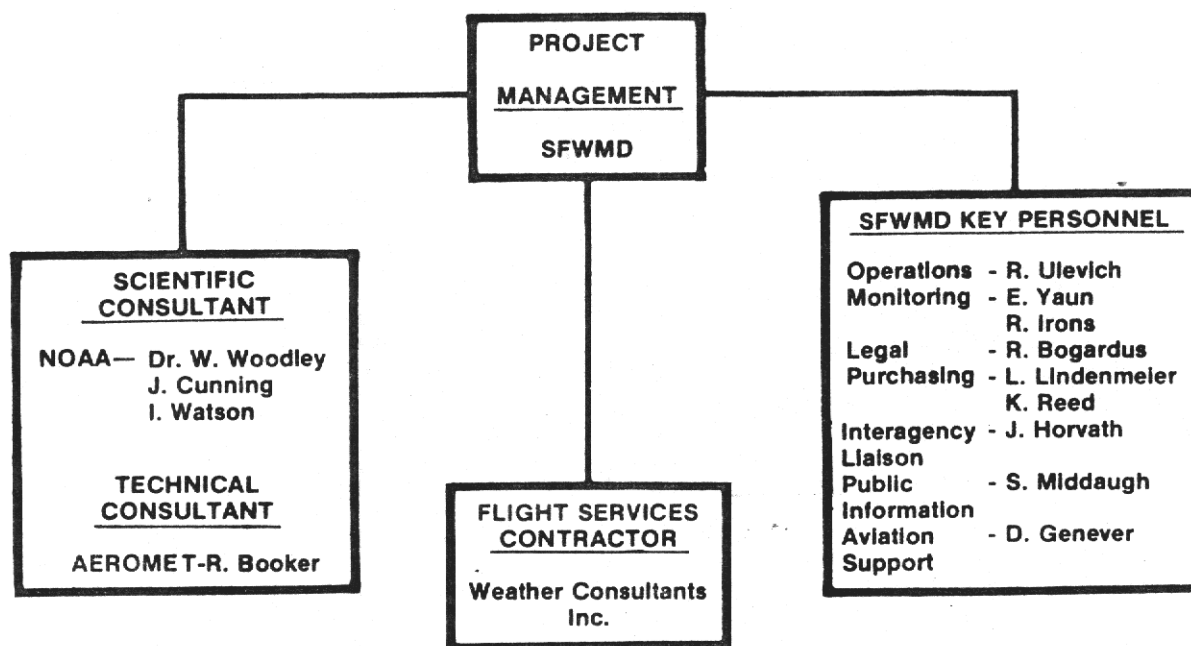
The scientific consultant (NOAA) provided experienced meteorologists from their recently concluded FACE program. They flew with each Flight Services Contractor crew to familiarize them with cloud seeding techniques and operations. In addition NOAA assisted during each day's decision-making and debriefing.

The Technical Consultant advised Project Management on instrumentation requirements and capabilities as well as overall operational procedures.

The Flight Services Contractor provided all flight personnel and equipment, and necessary ground support. On the average about 9 personnel participated in the daily missions.

SFWMD personnel worked on 2WM as additional duties outside of their normal responsibilities and contributed to all aspects of project activities.

### KEY FUNCTIONS - PROJECT 2WM



## FUTURE CONSIDERATIONS

The emergency nature of Project 2WM did not allow time for programming activities that would have been useful in the assessment of cloud seeding results, (such as "randomization" or control area techniques). Some consideration should be given to these areas for future programs.

The method of contracting out all essential flight services used on 2WM is only one way to do a cloud seeding program. It would be more cost-effective for the SFWMD to take on more of a "Prime Contractor" role, rather than contracting out all work.

There may be other seeding methods and agents that could prove productive in the Florida environment, such as carbon dioxide seeding.

It is well known that a drought period is the least productive time to conduct cloud seeding operations (due to the absence of necessary cloud cover/moisture). The District should consider the advantages of programming a longer-term period for cloud-seeding, such as a five to seven year period, during which time the results of the seeding could be more adequately assessed.